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RESEARCH MEMORANDUM

AN EVALUATION OF AIR-BORNE RADAR AS A MEANS OF
AVOIDING ATMOSPHERIC TURBULENCE

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NATIONAL ADVISORY COMMITTEE
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AN EVALUATION OF AIR-BORNE RADAR AS A MEANS OF

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SUMMARY

Gust-velocity measurements and air-borne-radar observations obtained during a transcontinental flight in July 1947 have been analyzed as part of a general investigation of the uses of air-borne radar. The analysis indicates that some reduction in turbulence and a consequent reduction in the risk of encountering the larger gust velocities may be obtained by avoiding portions of clouds giving a radar echo.

INTRODUCTION

The use of radar, both ground and air-borne, has been suggested as a possible means of detecting regions of atmospheric turbulence. The effectiveness of this means of turbulence detection depends, of course, on the amount of reduction of turbulence which may be expected by the use of radar. An analysis to determine the relative intensity within areas of radar echo, using ground-radar equipment, and in the surrounding air, using data from the Thunderstorm Project (reference 1), has indicated that an appreciable reduction in gust experience can be achieved by circumnavigation of areas of radar echo caused by air-mass convective storms (reference 2).

American Airlines, under a contract to the Bureau of Ships, Department of the Navy, has been engaged in obtaining data on various uses of air-borne radar in routine operating conditions. The NACA was requested to participate in the turbulence-detection phase of the work.

Acceleration measurements and radar observations were taken during a transcontinental flight of an American Airlines' airplane in July 1947. Although sufficient data were not obtained to give adequate results for application to airline operations, the acceleration data have been analyzed in relation to the radar data to show, for the test conditions, the intensity of turbulence in regions of radar echo within a cloud, in regions not giving a radar echo within a cloud, and in the surrounding air.

APPARATUS AND TEST CONDITIONS

The characteristics of the airplane used in the present investigations are given in table I. The airplane was equipped with a modified AN/APS-10 radar which was used in making all the radar observations.

The instruments installed in the airplane to determine the gust velocities were:

- (1) NACA air-damped recording accelerometer
- (2) NACA airspeed-altitude recorder
- (3) NACA synchronous timer (3-sec interval)

These optical-type recording instruments were installed in a group within the cabin of the airplane approximately 4 feet forward of the center of gravity. The pitot and static lines of the airspeed-altitude recorder were connected to the corresponding lines on the copilot's instrument panel. The film speeds on both recording instruments were generally adjusted to 16 inches of record per minute, although a few records were taken at a film speed of 4 inches per minute. Time synchronization between the two sets of records was obtained by the timer. Reference marks to denote different events such as cloud entry or exit were impressed upon the records by means of a switch operated by a flight observer.

The gust-velocity measurements and radar observations were taken during operations on the routes summarized in table II. As indicated in the table, the weather conditions generally consisted of stable air masses. The data used in the evaluation of air-borne radar, however, were taken in air-mass convective-type clouds and small thunderstorms over the portions of the route listed in the same table. The flight in clear air near the cloud and the flight through the cloud were made at approximately the same altitude, for a given cloud formation. The average flight altitude was 8,000 feet although some data were taken at altitudes from 4,000 to 13,000 feet.

Acceleration data were taken during flight in the vicinity of and through various cloud formations which gave radar echo to determine whether the portion of cloud giving radar echo was more turbulent than the portion of the cloud not giving a radar echo. In addition to these data, records were taken whenever rough air was encountered. In all, a total of about 11 hours of record was obtained with 9 hours representing flight over the southwestern portion of the United States in clear air not in the vicinity of clouds.

EVALUATION OF DATA AND RESULTS

The records of airspeed, altitude, and acceleration were evaluated to obtain the effective gust velocity U_e for each acceleration peak corresponding to an effective gust velocity of 2.0 feet per second or greater by use of the formula (reference 3)

$$U_e = \frac{2\Delta n W}{\rho_0 \alpha V_e S K}$$

in which

U_e	effective gust velocity, feet per second
Δn	acceleration increment, g
W	weight of airplane at the time the acceleration increment was experienced, pounds
ρ_0	air density at sea level, slugs per cubic foot
α	slope of lift curve, per radian
V_e	equivalent airspeed, feet per second
S	wing area, square feet
K	gust-alleviation factor (taken from fig. 1 of reference 3)

The effective gust velocities obtained were grouped according to zones representing area of radar echo in clouds, area of clouds but not in radar echo, area of clear air near clouds, and area of clear air over the south-west United States. The area of clear air near clouds encompassed an area up to about 10 miles from the cloud although normally the area was within 0 to 6 miles of the cloud. The results are shown as frequency distributions in table III for gust-velocity intervals of 2 feet per second. Table III also shows the record time, miles flown, and gust spacing in each of the weather conditions.

For ease in interpreting the results, the frequency data have been referred to a mileage scale in figure 1. This figure shows the number of miles that were flown for the various weather conditions to encounter a gust equal to or greater than the given values.

PRECISION

Errors in the computed values of effective gust velocity are felt to be less than about ± 5 percent. These errors rise primarily from inaccuracies involved in the acceleration and airspeed measurements. Other contributing factors are the lack of knowledge of the exact airplane weight at the time each gust was encountered and the effect of angular accelerations due to pitching motions of the airplane on the normal acceleration measurements.

DISCUSSION

Although sufficient data are not available to obtain conclusive evidence, the results given in table III indicate that some differences exist in the magnitude and frequency of gusts in the various flight areas. The over-all number of gusts of all intensities encountered per mile of flight is also greatest in the cloud radar echo as indicated in table III by the gust spacing of 0.087 miles in cloud radar echo and values up to 0.73 miles in clear air near clouds.

These results are further indicated by the mileage values of figure 1. It will be noted from this figure that the average number of miles that were flown in radar cloud echo to encounter a gust equal to or greater than a given value are from about one-half to one-third the number of miles that were flown in nonradar portions of clouds to encounter a gust of equal intensity. The ratio of the mileages for the other flight areas shows greater differences. In spite of the smallness of the samples, therefore, the data indicate that some reduction in the intensity and frequency of gusts might be obtained by avoiding areas of radar echo.

As a matter of interest, it can also be noted from table III that the gust spacing was considerably smaller (and the number of gusts per mile therefore greater) for the clear air over the southwestern United States than for the clear air near clouds. This smaller gust spacing is due to the large number of small gusts (gusts less than 10 ft/sec) encountered in the clear air over the southwest portion of the United States.

CONCLUDING REMARKS

Measurements of atmospheric turbulence and radar observations taken during a transcontinental flight indicate that some reduction in turbulence

and a consequent reduction in the risk of encountering the larger gust velocities might be obtained by avoiding portions of clouds giving radar echo.

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1. Anon.: Operation and Activity of the Thunderstorm Project to September 20, 1946. Rep. No. 1, U. S. Weather Bur., Thunderstorm Project, Nov. 1946.
2. Press, H., and Binckley, E. T.: A Preliminary Evaluation of the Use of Ground Radar for the Avoidance of Turbulent Clouds. NACA TN No. 1684, 1948.
3. Rhode, Richard V., and Donely, Philip: Frequency of Occurrence of Atmospheric Gusts and of Related Loads on Airplane Structures. NACA ARR No. L4I21, 1944.

TABLE I

CHARACTERISTICS OF TEST AIRPLANE

Average gross weight at take-off (estimated), lbs	26,000
Wing area, sq ft	988
Wing loading at take-off, lbs/sq ft	26.32
Span, ft	95
Mean aerodynamic chord, ft	11.5
Slope of lift curve, per radian	4.79



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